

Instrumentation for the Citizen CATE Experiment: Faroe Islands and Indonesia

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Abstract. The inner regions of the solar corona from 1-2.5 R_{sun} are poorly sampled both from the ground and space telescopes. A solar eclipse reduces the sky scattered background intensity by a factor of about 10,000 and opens a window to view this region directly. The goal of the Citizen *Continental-America Telescopic Eclipse* (CATE) Experiment is to take a 90-minute time sequence of calibrated white light images of this coronal region using 60 identical telescopes spread from Oregon to South Carolina during the 21 August 2017 total solar eclipse. Observations that can address questions of coronal dynamics in this region can be collected with rather modest telescope equipment, but the large dynamic range of the coronal brightness requires careful camera control. The instruments used for test runs on the Faroe Islands in 2015 and at five sites in Indonesia in 2016 are described. Intensity calibration of the coronal images is done and compared with previous eclipse measurements from November & Koutchmy (1996) and Bazin et al. (2015). The change of coronal brightness with distance from the Sun seen in the 2016 eclipse agrees with observations from the 1991 eclipse but differ substantially from the 2010 eclipse. The 2015 observations agree with 2016 and 1991 solar radii near the Sun, but are fainter at larger distances. Problems encountered during these test runs are discussed as well the solutions which will be implemented for the 2017 eclipse experiment.

1. Introduction

The path of totality of a solar eclipse will cross over 10 million homes in the USA during the late morning and early afternoon on Monday 21 August 2017. Tens of millions more people will travel to view the total eclipse and hundreds of millions more will directly view the partial eclipse. Using broadcasts hundreds of millions of people will watch the total eclipse, from school children through senior citizens. From one location during the 2017 eclipse the corona will only be revealed for about 2.5 minutes; this short time does not allow detailed study of slower changes in the corona (Lites et al., 1999). From the moment the lunar shadow touches Oregon until it leaves South Carolina 90 minutes of time will elapse. The Citizen *Continental-America Telescopic Eclipse* (CATE) Experiment will use 60 identical telescopes positioned across the country to image the solar corona. The CATE goal is to collect calibrated white-light image of the solar corona from about $1 R_{sun}$ to $2 R_{sun}$ with about 2 arcsecond pixels every 10 seconds continuously for 90 minutes.

Using data from the Spartan 201-01 mission in 1993, Fisher and Guhathakurta (1995) measured white light polar plumes above the northern and southern solar coronal hole. These plumes extended from the lower limit of the occulting disk at $R = 1.25 R_{sun}$ up to over $5 R_{sun}$. Simultaneous ground-based measurements from Mauna Loa suggested that the plumes extended down to $R = 1.16 R_{sun}$. The directions of the plumes, while appearing roughly radial, did not intersect the center of the solar disk but rather seemed to originate at higher latitudes. Later work by DeForest and Gurman (1998) traced these structures down to magnetic features at the solar poles using SOHO EIT 171A data, and measured a size of between 3-5 arcsec. The CATE data will measure these structures in white light with 2 arcsec pixels to very low heights of $R = 1.05 R_{sun}$, and out to the edge of the field-of-view at $2 R_{sun}$. Using simultaneous magnetograms from other telescopes, these polar plume structures can be traced using the continuum signal from coronal electron density enhancements back to the Sun with better resolution than previous studies.

At solar minimum structures called polar plumes are clearly visible above the magnetic north and south poles of the Sun. These regions have been found to be very dynamic. DeForest and Gurman (1998) used SOHO EIT 171A observations to observe outwardly moving density enhancements traveling at 75-150 km/s velocity, showing brightness changes of 5 to 10%, and displaying periodicity at 10-15 minute periods. Cranmer (2004) estimated 3 to 15% variations in the electron density in these events. Using UVCS observations at two alternating heights in the corona $R = 1.9 R_{sun}$ and $2.1 R_{sun}$, Ofman et al (2000) found quasi-periodic variations of 5 to 10% in polarized brightness traveling radially at 210 km/s with periods between

6.5 and 10.5 minutes. Morgan et al (2004) used Lyman alpha data out to $2.2 R_{sun}$ to find oscillations with 7 to 8 minute periods. With SUMER disk observations of Ne VIII emission, Gupta et al (2012) found 5-10% intensity oscillations traveling at 60 km/s with a period of 14.5 minutes. From eclipse observations, Pasachoff (2009) found changes in the corona above the southern solar pole. But since this observation used only two images taken 19 minutes apart, it is difficult to find systematic radial motion. With 540 images taken at 10 second cadence across 90 minutes, the CATE data will have direct applications to the study of polar plume dynamics. Periodicities at the 15 minute time scale will be fully sampled, and the velocities and accelerations of these events will be measured from $R = 1.05 R_{sun}$ out to at least $2 R_{sun}$. The CATE data will be sensitive to transverse velocities of roughly 0.8 to 145 km/sec (3pix/90 min to 1 pix/10 sec) and will easily measure these events.

In addition to showing polar plumes, the solar minimum corona which will be seen during the 2017 total solar eclipse will likely show several prominences. The interaction of the hot corona with the cold prominence plasma has been studied recently. With the Hinode SOT instrument Berger et al (2007) show upwardly moving hot gas parcels, thought to be Rayleigh-Taylor instabilities in the prominences. Typical sizes which were observed were about 2250 km, and these features showed upward speeds of roughly 20 km/s. Using lower resolution white-light images of the hot coronal plasma, Druckmuller et al (2014) examined a static structure observed near a prominence called a smoke ring. The authors speculate that these structures are related to the RT instabilities seen in prominences. The CATE data will reveal and motions of these new coronal structures during the 90 minutes of the eclipse, and will have a transverse velocity sensitivity that covers the expected 20km/s motion. The CATE observations may reveal how the instabilities seen in prominences interact with the hot corona and produce density enhancements or depletions such as these smoke rings.

In preparation for the 2017 CATE experiment, two test runs have been completed at the total solar eclipses in 2015 and 2016. Equipment similar to the 2017 instrument was used in each case by citizen scientists and first-time eclipse observers. We describe the results of these tests and plans for the 2017 experiment in the following paper.

2. CATE Instruments

The overall goal of the project is to develop a low-cost instrument from off-the-shelf components that are readily available to citizen scientists, while maintaining

the scientific capability required to address the key science questions discussed previously.

2.1. General

A detailed description of how the science goals for the CATE data map into instrument requirements is given in Penn, Baer & Isberner (2015), but we review the main constraints here. For a simple and inexpensive design with high throughput that will remain flexible for use after the eclipse, the instrument camera will be at prime focus. In order to resolve 2 arcsec structures in the corona at a wavelength of 600nm, the aperture of the telescope must be greater than 60mm, but reasonable cost constraints and portability requirements limit the aperture to less than 120mm. For an image across a large field-of-view of roughly 4000 x 4000 arcsec that has good chromatic correction, the objective lens should be about f/5 or slower. Finally by examining currently available detectors in this price range, the objective focal length should be shorter than about 800mm in order to fit the desired FOV on the detector.

2.2. Telescopes, Mounts and Cameras for the 2015 and 2016 instruments

In both 2015 and 2016 eclipse experiments, a German Equatorial mount from Celestron, Inc. (model CG4) and a battery powered RA drive was used to track the Sun during the eclipse. This was the only item that was the same in these two experiments. The mounting legs were modified for ease of transport during the 2016 eclipse.

In the 2015 eclipse, the telescope used was a Lunt 80mm diameter 560mm focal length refractor (model LE-80 OTA) with an ED Doublet lens. The camera was the Point Grey Grasshopper 3 USB3 CMOS device using a 2048x2048 CMOSIS CMV4000 array (model GS3-U3-41C6M-C) with 5.5 micron pixels. The predicted image scale is 2.03 arcseconds per pixel. The control computer had a 1.9GHz processor running Windows 8, with 4Gbyte RAM and a 1 TByte disk drive.

For the 2016 eclipse, the telescope used was a Daystar 80mm diameter 480mm focal length refractor (model 480E) During testing of the telescope we noticed residual chromatic aberration and added a Wratten #58 filter (Peel, 2009) in the optical beam just in front of the camera to sharpen the image by minimizing the focus variation over the restricted bandpass. The camera was the Point Grey Grasshopper 3 USB3 CMOS device using a 2448x2048 Sony IMX250 array (model GS3-U3-51S5M-C) with 3.45 micron pixels. The predicted image scale is 1.48 arcseconds per pixel. The control computer had a 1.7GHz dual processor running Windows 10, with 16 Gbyte RAM and a 105 Gbyte solid state drive.

2.3. Data Collection software: exposure sequence, dead-time, duty cycle

The data collection software varied dramatically between the tests at the two eclipses. In the 2015 eclipse, the demonstration software Flycapture provided by Point Grey was used to collect calibration and coronal images. The eclipse observing plan was to expose the camera for a short exposure value for the first 30 seconds of totality to capture the inner corona, then to manually switch the exposure time to a longer value and observe the outer corona for another 30 seconds. Unfortunately, clouds prevented any images from being collected with the longer exposure value.

For the 2016 eclipse calibration data was collected using a freeware routine called Firecapture. Dark and flat field images (of the daytime sky) were collected. A drift scan was run where the RA drive motor was turned off and images were collected once per second as the solar image drifted across the FOV; in this way it is possible to determine the direction of geocentric West in pixel coordinates for each site. The control computer clock was set to GPS time within 30 minutes of the start of totality at each location; tests showed that the CPU clocks drifted about 50 milliseconds per hour, so that the times for the exposures at each site would be calibrated to about 25 milliseconds. During totality, a data collection program written in Matlab used the hardware trigger mode of the 51S5M-C to take a set of 7 different exposures. Exposure times of 0.4, 1.3, 4.0, 13, 40, 130 and 400 milliseconds were used to capture the expected dynamic range of the corona across the FOV. The camera expose pulse was generated by an Arduino UNO R3 microcontroller providing an output strobe into the GPIO input of the 51S5M-C camera. The Arduino sketch produced pulses for each of the 7 exposures, with a 30 millisecond delay and between each exposure and a longer 200 millisecond delay between each cycle. The longer cycle delay time was required in order for the control computer to write all seven images to the SSD. Overall during 968.7 milliseconds of time the camera was exposing for 588.7 milliseconds, representing a 61% duty cycle. Throughput to the computer disk was measured at about 7 frames per second. The image display during totality lagged the data collection, and so attempts to update the telescope pointing at the HM Volendam site (to correct for ship motion) were impossible.

3. 2015 Faroe Islands

The March 2015 eclipse observations were suggested by Fred Isberner in August of 2014. Isberner trained with the eclipse instrument for just a few days in February of 2015, and then he traveled to the eclipse at his own expense during a vacation.

3.1. Site, conditions, instrument

The path of totality for the total eclipse of 20 March 2015 crossed the northern Atlantic Ocean, intersection land at only the Faroe Islands and Svalbaard. Observations with the first CATE prototype telescope were taken at the Vagar Airport Hotel in Sorvagur on the island of Vagar in the Faroe Islands at 62.0669N, and 7.2812W. The observers were Fred Isberner and Howard Harper. Conditions at this location were very poor, with rain and clouds during most of the partial phase and only a few short partly cloudy gaps before and during totality. Duration of totality at this location was was predicted to be 137 seconds.

Through the partly cloudy conditions a sequence of over 800 images of the partially eclipsed Sun were taken with a neutral density solar filter covering the primary lens between second and third contact. The extinction factor of this filter was estimated by comparing the observed solar intensity with the filter on to the observed intensity of the Moon, Mars, Jupiter and Saturn with the filter off on 30 January 2015. A linear fit of the observed intensity ratios to the predicted intensity ratios suggests an extinction factor of about 1.05×10^5 . These images are used to derive the measured solar disk brightness for calibrating the coronal images. The solar limb was fit and the radius was measured at 477.02 pixels which gives an image scale of 2.02 arcseconds per pixel. After second contact, the same exposure value was used to capture 37 useful images of the inner corona after removing the neutral density filter. The observing plan was to take a second image sequence during totality with a longer exposure time, but the weather conditions prevented this sequence. The 37 short exposure images were co-aligned and then coadded. The lunar limb was fit and the radius was measured to be 497.50 pixels which again suggests an image scale of 2.02 arcseconds per pixel. Using the center of the moon in this summed totality image as the origin, a normalized radial-graded filter (NRGF, Morgan, Habbal & Woo, 2006) was computed to determine the average intensity with radius, and to filter the eclipse image to enhance the coronal structure. The filtered image is shown in Figure 1.

4. 2016 Indonesia Network

With support from NASA funding, four university students were selected and traveled to the National Solar Observatory in Tucson in January 2016. For two days the students assembled their telescopes, took sample solar data with the cameras and laptops, and learned some basic ideas about the solar corona and eclipses. None of the students had observed a solar eclipse previously, and none had traveled outside

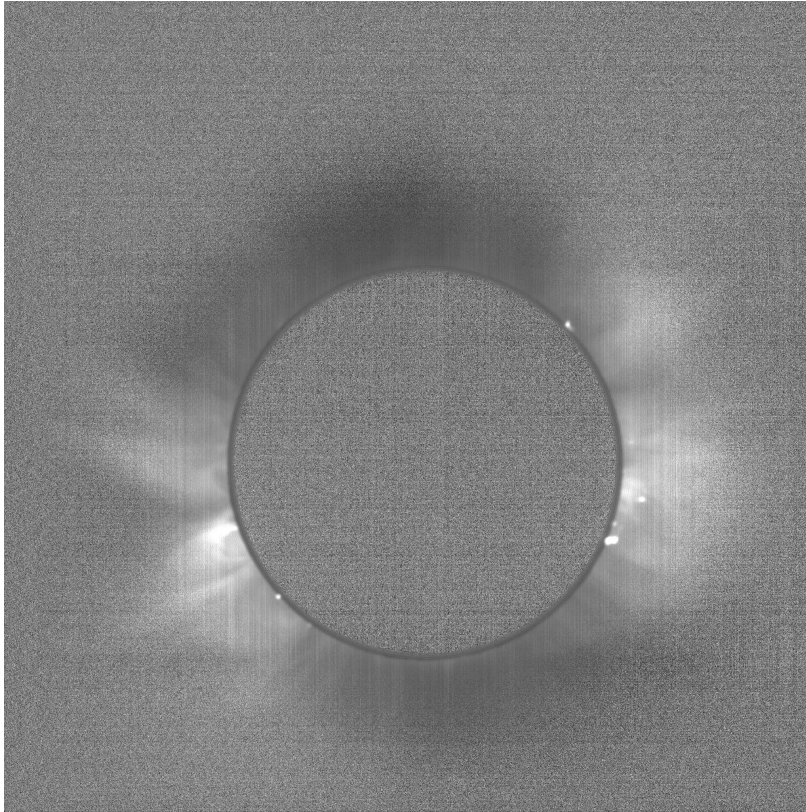


Figure 1. Image of the solar corona from Vagar on the Faroe Islands during the 2015 eclipse taken by Fred Isberner. A normalized radial-graded filter has been applied to the sum of 31 co-aligned images from the observations.

of the USA. A fifth group of citizen scientists traveling to the eclipse at their own expense volunteered to take data as well.

4.1. Sites, conditions, instruments

The Indonesian eclipse experiment consisted of five sites along the path of the total eclipse.

The first site was in Tanjung Pandan on the island of Belitung. Data collection occurred at 2.7433S, 107.6233E in a park along the west coast of the island bordering the Java Sea. The observers at this site were Sarah Kovac and Bob Baer. Observing conditions were clear with small clouds. There were no instrument problems and the images were focused well. Duration of totality was predicted to be 124 seconds.

The second site was located in the city of Tanah Grogot atop the RSUD P. Sebaya hospital at 1.8729S, 116.1790E. The observers at the site were Dr. Michael Pierce

and Logan Jensen. The weather conditions were calm but with obstructing clouds during totality. Instrument behavior during the parts of the procedure performed was good, however no data was acquired due to obscuring rain clouds. Duration of totality was 153 seconds.

The third site was located on the cruise ship MS Volendam operated by Holland America Line. During totality the ship was located roughly at 1.5983S, 118.0433E in the Makassar Strait between Kalimantan and Sulawesi. The observers at this site were John Varsik, Fred Isberner and David Young. Observing conditions were clear. Instrumentation problems during setup resulted in defocussed images, saturated calibration data, and incorrect time-of-day values for images since the GPS software failed. Finally waves during totality resulted in image motion of up to several degrees during the observations. Duration of totality was 160 seconds.

The fourth site was on the island of Sulawesi in Palu. Observing occurred on the roof of a building on the eastern outskirts of the city at approximately 0.8883S, 119.9100E. The observers at this site were Richard Gelderman and Honor Hare. Observing conditions were clear with rare clouds. The calibration images were over exposed before the eclipse began. Also, the eclipse images were highly defocused and the sun off center. Duration of totality was 119 seconds.

The fifth site was island of Ternate. Data collection occurred at roughly 0.7958N, 127.3614E on a hotel room balcony on the east coast of the island. The observers of this site were Myles McKay and Don Walter. Observing conditions were cloudy but had a small break in the clouds during totality. There were no instrument problems, but the images are defocused since very little time was available to focus the telescope during the partial phase of the eclipse due to the clouds. Duration of totality was predicted to be 160 seconds.

During the partly cloudy conditions at Tanjung Pandan, calibration data was obtained between first and second contact using a neutral density filter. The solar limb was fit and measured an image scale of 1.48 arcseconds per pixel. The center was saturated. Data from the HM Volendam had no clouds during the calibration or totality observing phases. The solar limb was fit and measured an image scale of 1.49 arcseconds per pixel. The totality data from Tanjung Pandan showed the best focus and image stability. Roughly 1038 coronal images were collected during totality. A set of 7 exposures were used to make a high-dynamic range image by subtracting dark exposures, excluding saturated pixels and scaling by the correct exposure time. In pixels where several images contained valid data, the scaled values were averaged. A fit to the lunar limb was done, resulting in an image scale measurement of 1.49 arcseconds per pixel. Figure 2 shows a sample of the data; it is a high-dynamic range

image constructed from seven individual exposures with a NRGF filter applied to bring out coronal structures.

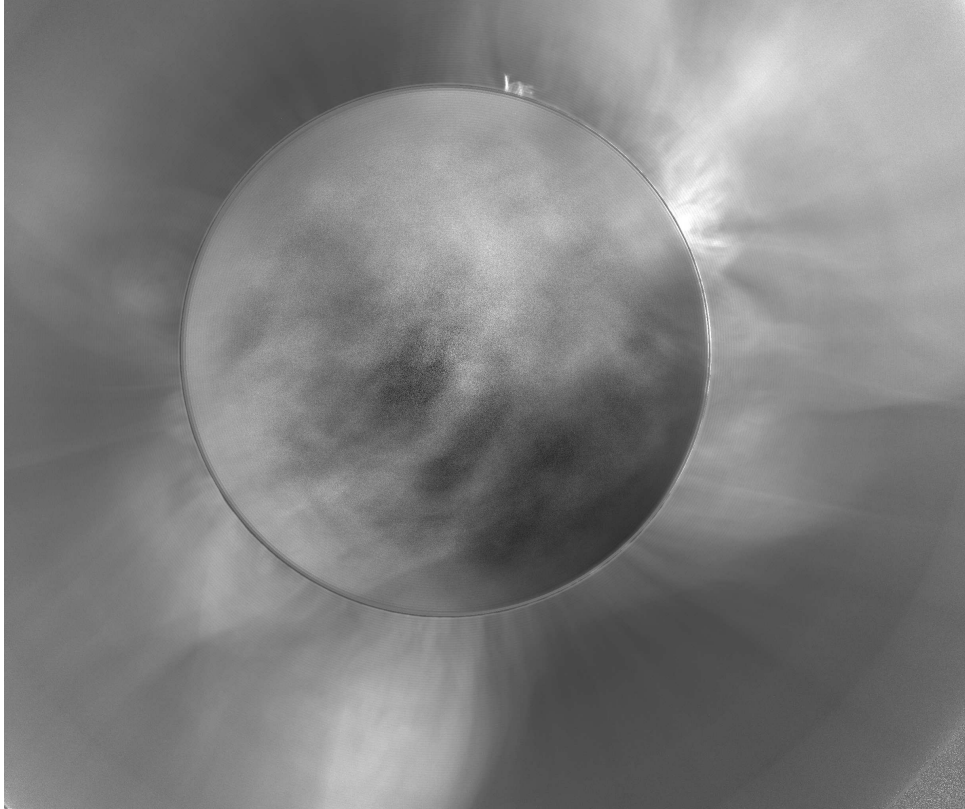


Figure 2. Image of the solar corona from the Indonesian 2016 eclipse taken by Bob Baer and Sarah Kovac. A normalized radial-graded filter has been applied to the high-dynamic range image composed from a single set of seven exposures.

5. The Intensity Calibration

With intensity images of the solar disk taken shortly before third contact, and with a measurement of the extinction provided by the neutral density filter, calibrated measurement of the coronal brightness is possible. This is the goal for the data collected at all the sites in the 2017 eclipse experiment.

During tests in 2015 and 2016, the extinction of the neutral density filters were measured using night-time observations as discussed in the previous sections, and images of the partially eclipsed solar disk were taken before totality. Unfortunately several complications were encountered. From the five sites of coronal data, three had partly cloudy conditions, two had saturated pixel values at the center of the

solar disk, and one had images taken well after first contact which do not include the center of the solar disk. In this section we discuss methods to overcome some of these problems.

For the sites with partly cloudy condition (Faroe Islands, Tanjung Pandan and Ternate) the only possibility is to assume that the calibrated data had equally cloudy conditions. This assumption is probably not correct, but it is the best that can be done.

In order to find intensity values at disk center when the camera pixels were saturated, and to estimate the sun-center brightness in late phases of the partial eclipse, we make the assumption that the measured limb darkening with each instrument is identical. With the four sites from Indonesia this is a good assumption since they are each measuring the solar disk at the same wavelengths, those transmitted by the Wratten #58 filter. It is not strictly correct to directly compare the Faroe Islands data with the Indonesian data since the wavelengths sampled are different and the expected limb darkening function is not identical, but we make the comparison anyway to estimate the disk center brightness for the Faroe Islands data. The comparison of the measured solar disk intensity for the Faroe Islands (Vagar), Volendam and Tanjung Pandan data is shown in Figure 3.

The Tanjung image was scaled to the Volendam image using intensities from $0.9 R_{sun} < r < 0.97 R_{sun}$, and the Vagar image was scaled across the range of from $0.6 R_{sun} < r < 0.97 R_{sun}$. While the Volendam and Tanjung images were taken at the same wavelengths and have very similar limb darkening profiles, the Vagar image was taken at a longer wavelength and only approximately matches the Volendam limb darkening. Using the measured value for the neutral density filter extinction of 27000, accounting for a 38mm aperture stop used over the telescope primary lens, and accounting for exposure time, the Volendam calibration images suggest a count rate of 145×10^9 ADU pixel⁻¹ second⁻¹. Accounting for the measured scaling factor of 1.092 between the Volendam and the Tanjung images at the solar limb, the Tanjung count rate is extrapolated to be 158×10^9 ADU pixel⁻¹ second⁻¹ at solar disk center. Finally, after fitting the Vagar data to Volendam, the extrapolated count rate at disk center for the 2015 data is 1.90×10^9 ADU pixel⁻¹ second⁻¹.

6. Average Coronal Brightness

Using the mean intensity of the corona computed during the NRGF image filtering, and scaling by the intensity calibrations measured from the solar disk images, we compute the calibrated azimuthally averaged coronal brightness. The measured Vagar coronal brightness is about a factor of eight brighter than the Tanjung

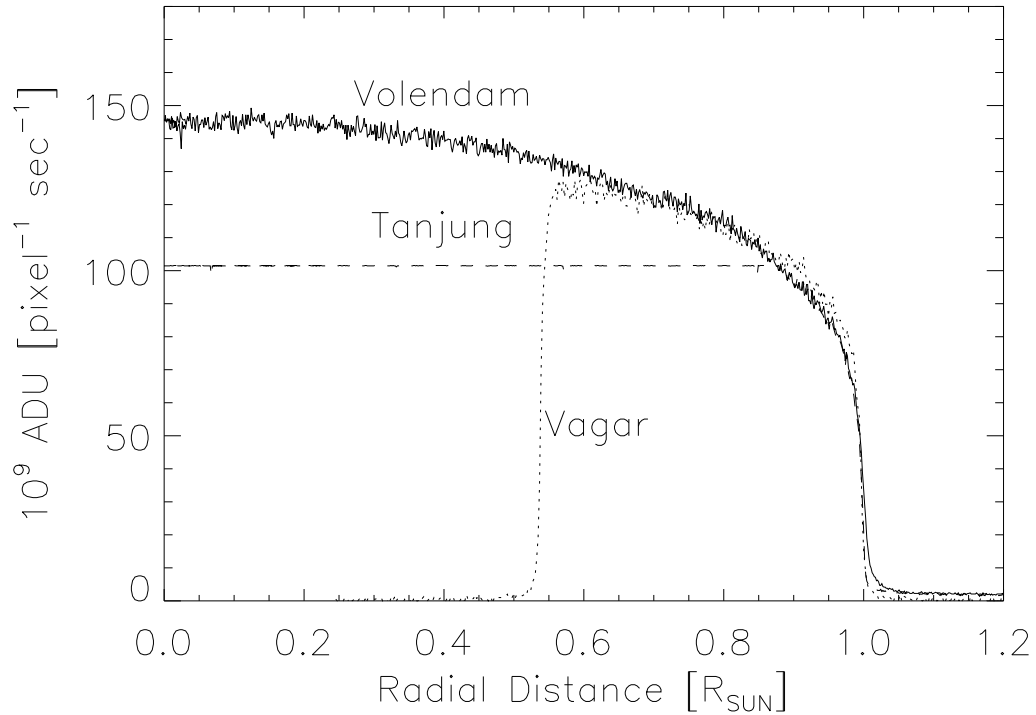


Figure 3. Solar limb profiles from Volendam, Tanjung, Vagar. The Volendam calibration image captures the solar disk from sun center to the limb and beyond; the Vagar image was taken later in the eclipse and the lunar limb blocks the Sun below about $0.55 R_{sun}$ the Tanjung image saturates on the disk from the sun center out to about $0.87 R_{sun}$.

brightness; this is likely to have been caused by a change in the camera gain setting during the totality observations 2015. After accounting for this offset the coronal brightness behaves identically in the two data sets from about $1.07 R_{sun}$ to $1.8 R_{sun}$, after which the 2015 coronal brightness drops faster with increasing distance. Figure 4 plots these coronal brightnesses, but each observation has been scaled differently; the brightness from Vagar has been multiplied by a factor of 6.3 and the brightness from Tanjung has been multiplied by a factor of 79. Also included on this plot are coronal intensity values measured from the 1991 eclipse by November & Koutchmy (1996), and equatorial and polar coronal brightnesses reported by Bazin et al. (2015). The Tanjung data precisely fit the values from November & Koutchmy (1996) when they are multiplied by a factor of 63, but the Vagar values drop more quickly than any of the previously reported measurements

after a solar radial distance of about $1.8 R_{sun}$ perhaps due to the cloudy conditions. It is likely that the differences in the absolute brightness calibrations are caused by a combination of incorrectly measuring the extinction of each neutral density filter and by the clouds at both eclipse sites.

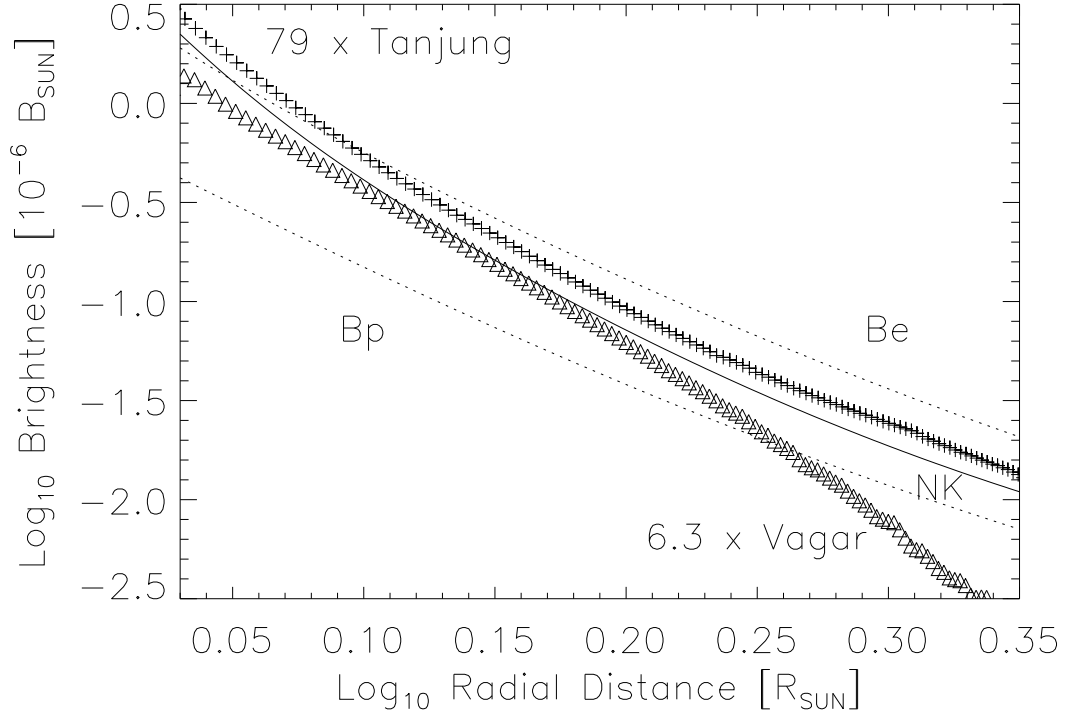


Figure 4. The calibrated azimuthally averaged coronal brightness from the 2015 Vagar eclipse observations compared with the 2016 Tanjung observations. The Tanjung data have been multiplied by a factor of 79, and the Vagar data by a factor of 6.3. Also shown are measurements from November & Koutchmy (1996) (solid line, NK) and Bazin (2015) (Be is a reported 2010 equatorial coronal brightness, and Bp is a reported 2010 polar coronal brightness). The Tanjung data fit the November & Koutchmy (1996) measurements very closely if they are multiplied by a factor of 63.

7. The 2017 Eclipse Instrument

Our experiences in 2015 and 2016 have pointed to a few problems which must be addressed with the 2017 instrument. The telescope objective must have better chromatic correction, the solar brightness data must be taken with a calibrated filter

and must not be saturated, and the images of the Sun and the eclipse must be in focus. Additionally, the operations of the timing and GPS software should be more reliable.

7.1. Instrument outline

The overall instrument design will remain nearly identical to the 2015 and 2016 telescopes; an 80mm diameter 400-500mm focal length refractor will be used. Daystar Filters Inc has prepared a new glass prescription for the objective lens which will result in much less chromatic aberration. The manual focus mechanism will remain, as will the German Equatorial tripod mount. We expect to use the same (or similar) digital cameras and very similar control computers.

7.1.1. New Matlab GUI A new graphical user interface is being written in *Matlab* which will aid the observers in collecting both the calibration data and the totality data. This GUI will address the three remaining problems uncovered during our two years of tests. First, an intensity histogram of the calibration images will be shown to the observers, and software checks will be introduced to make sure that the calibration images are not saturated. The neutral density calibration solar filter will be supplemented with an aperture stop with a calibrated pinhole. Second, a new focus routine has been written to give an objective feed-back to the CATE observer. The routine measures the intensity gradient across the solar image, and provides a real-time measurement of the maximum value of the gradient. The CATE observer will maximize this value during the partial phase of the 2017 eclipse in order to obtain a good focus for the telescope. Finally a new shield board will be added to the Arduino camera controller. This shield will have a GPS module which will obtain a GPS position and time, but also provide a pulse-per-second output to the data collection software. In this way, each site in the 2017 network will collect an HDR image sequence starting at even GPS seconds. Thus all of the 2017 data will be temporally calibrated.

Software which will provide a quick-look at the 2017 eclipse data is currently being developed. The goal is to reduce the drift-scan data to determine the image rotation at each site, and then to select a set of seven exposures from the totality observations to construct an HDR image. This HDR image will then be rotated and aligned at each CATE site in 2017 using the control computer (after the eclipse data has been backed-up) and then uploaded to a web site to produce a movie of the observations on the day of the eclipse.

7.2. The 2017 CATE Sites

The sites for the 2017 CATE experiment have been selected and the volunteer observers for each location are established. Sites west of the Mississippi River have good weather forecasts, sites east of Mississippi have about a 50% chance of clear skies. Since the project would like to transfer ownership of the site equipment to the volunteers, the CATE equipment is being funded with private and corporate donations. Currently about 20 sites are funded, and we are trying to fund the equipment for all 60 sites soon. The plan is to have the 2016 eclipse volunteers act as trainers for the 2017 CATE volunteers. The video and hands-on training program has been tested at a local high school in Tucson AZ, who will be sending a team of 8 students to collaborate with another high school in Beatrice NE. The volunteers for the 2017 eclipse range in age from middle-school students through retired professional solar astronomers. The observing locations range from remote camp sites to college campus locations where tens of thousands of visitors are expected.

7.3. Data plan

Each CATE site is expected to produce about 10 Gbytes of calibration data and about 10 Gbytes of coronal images. Many locations will not have any internet access, and so it is expected that one copy of the data will be mailed to NSO offices. With a three-day delivery time, mailing the data results in about 5 Mbyte per second transfer rate, which seems acceptable. The data will be analyzed at the NSO centrally.

The quick-look images produced on each site laptop will be uploaded that day to the NSO; each image will be less than 10 Mbytes. A movie sequence of these images will be produced as soon as possible for education and public outreach purposes.

8. Future use on night-time objects

Since each of the CATE instruments will be transferred to the site volunteers, it is important to have follow-up citizen science programs for the telescopes so that the volunteers can continue to engage in citizen science for astronomy. A solar observing program is being investigated which would use an additional H-alpha filter, tuned with the Arduino controller, to produce full-disk dopplergrams for the chromosphere. Observing cometary light curves provides valuable information about evolution of comets but is infrequently supported at large facilities. A follow-up project collecting photometry on comets is being prepared for the CATE telescopes.

Finally the AAVSO is developing an instrument package which is similar in size and spatial resolution to the CATE instrument; a variable star observing program for the CATE instrument is being developed as well.

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